

# Project of a miniature 3D LIDAR for VTOL UAVs

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**Abstract:** An avionics module was developed based on a commercially available LIDAR, which perform scans in a single plane. The module enables to obtain three dimensional point map of the area around aircraft. Spherical coordinates of each point are forwarded to the main avionics computer, where final computations are done accordingly to the implemented algorithm. Received data can be used to determine areas dangerous for flight, specify flight trajectory that avoid obstacles or just for visualization of the aircraft surroundings. In this article designed structure of the module was presented as well as developed operational algorithm. Finally, obtained measurement results were discussed and usage constraints consequential to a specific structure of the module were presented.

**Keywords:** LIDAR, UAV, avionics module, anti-collision system

Nowadays autonomous flights are not as rare as they were in the last century. All manned aircrafts are equipped with sophisticated autopilots. Unmanned Aerial Vehicles (UAVs) become more and more popular for civil missions, which mostly include surveillance when onboard cameras are provided. Although, when flying outdoors, they can successfully follow pre-programmed routes relying basically on a GPS data, flying in urban areas or indoor is still a great challenge.

For this group of tasks it is impossible to develop algorithms of autonomous flights without a reliable source of information about obstacles around an UAV [1]. Recently for that purpose simple Light Detection And Ranging (LIDAR) sensors became often used, as their price and weight significantly decreased. What is more, this kind of sensor provides in short time an information about exact distance and heading to objects around it.

The main disadvantage is that due to simplicity, lightness and cheapness of a LIDAR construction measurements can be performed only in one plane. That scheme of measurements is dangerous because of possibility that not all obstacles may be detected.

## 1. Introduction

In the Department of Avionics and Air Armament at the Military University of Technology a three dimensional scanner was developed to eliminate that threat. The aim was to adopt a popular Hokuyo URG-04LX laser range finder to get a spatial information about surroundings. This unit was chosen, because it has been successfully used as a proximity sensor for UAVs in various research projects all over the world.

In the German IAIS Fraunhofer Institute, in cooperation with Bonn University of Applied Science, an emergency system was tested, where this sensor was used to prevent collision with walls in case of control signal lost [2]. Researchers from Dubai choose the same laser range scanner for their obstacle detection system of an UAV, that was designed for the International Aerial Robotics Competition [3]. Moreover, during an engineering project fund by the Wright Patterson Air Force Research Lab in Dayton in USA, a commercially available AR.Drone UAV was equipped with a custom sensor package to fulfil autonomous indoor exploration task [4]. One of those sensors used to build a map of the drone's surroundings was Hokuyo URG-04LX.

All of the mentioned projects have two common features. First is a usage of Vertical Take-Off and Landing (VTOL) UAV of a quadrotor class. That is because indoor flights require an ability of slow motion between obstacles and sometimes even to stop and hover. Second is a stationary position of the scanner, which, as was already mentioned, results in measurements only in one plane that preferably is situated a few millimetres above rotors.

## 2. Structure of the module

The designed avionic module is dedicated for a VTOL UAVs as well, but gives a possibility to achieve a 3D point map of surrounding. The 3D LIDAR structure (figure 1) consists of four main elements. First is the Hokuyo sensor (1) which is mounted to its housing (2). The sensor housing is driven by a servomechanism (4) which is attached to a module housing (3).

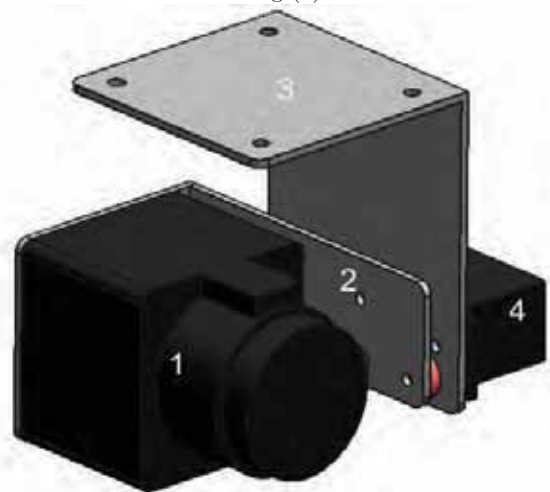


Fig. 1. Structure of the three-dimensional laser range scanner

Rys. 1. Struktura trójwymiarowego, laserowego skanera przestrzeni

## 2.1. Hardware specification

Both housings are made of aluminium to minimize weight (fig. 2). The module housing can be mounted on an UAV horizontally or vertically depending on a desired usage. Two main possible applications are concerned. First is a surface scanning which results with a spatial map that can be used to determine a possible landing field. Second is scanning the area ahead of a UAV giving information about obstacles in flight trajectory. The servomechanism used in the designed module can move  $180^\circ$ , so it is also possible that both modes can be applied if the 3D LIDAR is mounted in a proper place on a UAV. In that case the avionics system software must be able to switch between those modes adjusting the servomechanism's movement limits.



**Fig. 2.** Designed 3D LIDAR

**Rys. 2.** Zaprojektowany trójwymiarowy laserowy skaner przestrzeni

The servomechanism and Hokuyo scanner are connected to a 8-bit AVR microcontroller which is used to control the module and monitor data flow. Moreover, three axial gyroscope and accelerometer are connected to the microcontroller by SPI interface to add information about designed LIDAR instantaneous orientation. All configure and control commands are received from main avionics computer by UART interface and measurement data are simultaneously returned by the same port.

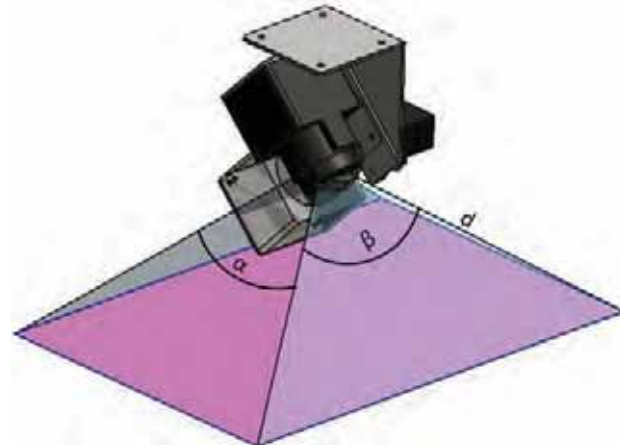
Detection range of Hokuyo scanner is approximately  $240^\circ$  determined by an exact number of 683 measurement steps with maximum measurable distance of 4095 mm [5]. Producer allows to freely change number of scanning steps but it does not change scanning time which is always 100 ms. The reason for that is a fact that spindle motor rotates at a constant speed of 600 rpm regardless number of steps. Furthermore, current consumption tests proved that it is always around 480 mA from the power-up through configuration and during measurements with various number of steps. In designed 3D LIDAR maximal laser scanning angle is limited by the module's structure to  $120^\circ$  that corresponds to 341 steps.

Although servomechanism can rotate  $180^\circ$ , such vast range significantly lengthen a single scan time of the designed module. It was assumed that module would be mounted either to obtain map of a surface beneath an

UAV or to scan area on a flight trajectory. First case leads to maximal reasonable values while for the second one, range can be minimized to dozens degrees. To determine optimal movement range for the servomechanism simple trigonometric calculations were done. Objects can be detected not further than 4 m from the sensor, while minimal secure operating height of UAV is around 2 m. Those values limits servomechanism to rotate  $60^\circ$  in both directions from the middle position. With those limitations maximal area covered by the scanner equals  $48 \text{ m}^2$  and a single scan last 12 s.

## 2.2. Software algorithm

Communication between main avionics computer and designed module begins with a configuration frame which includes three parameters: servomechanism angle ( $\alpha$ ), step size and laser scanning angle ( $\beta$ ) with a default values of  $120^\circ$ ,  $1^\circ$ ,  $120^\circ$ , respectively. Those are at the same time maximal allowed angles and minimal step. By changing those values scanning coverage (fig. 3) can be adjusted by the user accordingly to needs before every scan, significantly reducing scanning time.



**Fig. 3.** Scanning coverage of the module

**Rys. 3.** Obszar skanowany przez modul

After reading the configuration frame microcontroller monitors UART for a start-scan command from the main avionics computer. The command also informs about quantity of scans to be performed. Configuration data of the Hokuyo scanner is translated by microcontroller to SCIP protocol and send through USB interface to the device. Returned distance measurement data is decoded and combined with a servo position and sensor Euler angles. Instantaneous angles are computed before each scan to provide updated orientation of the unit.

Data frames created that way and received by main avionics computer contains all essential information for they later processing. For default settings a single scan results with more than 41 000 data frames with six parameters. Most important is distance to the detected object for each laser beam with its servo and sensor current angles  $\alpha$  and  $\beta$ . Additionally accurate orientation angles are determined to generate a precise spatial map. Without that information transformation from a spherical coordinate system, in which data is obtained, to a local Cartesian coordinate system would be erroneous.

The main avionics computer mentioned several times in this article is not an integrated part of the 3D LIDAR. Actually, it can be any digital circuit with UART interface. During various laboratory tests we used radio-modems, standard PC as well as embedded computer with a real time operating system. The latter was a main avionics module developed by our team during former researches. Integration of designed 3D LIDAR with that module resulted with a fully functional system for virtual spatial map creation.

### 3. Scanning results

Developed system was first tested stationary. The module was mounted on a tripod and a scan was performed. All measurement data converted to a local Cartesian coordinate system were stored in main avionics computer memory. The fastest way to verify correctness of the algorithms and measurements was importing obtained point cloud data to a CAD program handling such file. An expected result is a three dimensional visualization of sensor surroundings. Comparison of visualized measurement data and a picture of scanned area (fig. 4) proved that designed 3D LIDAR and its control program in a main avionics computer were successfully developed.

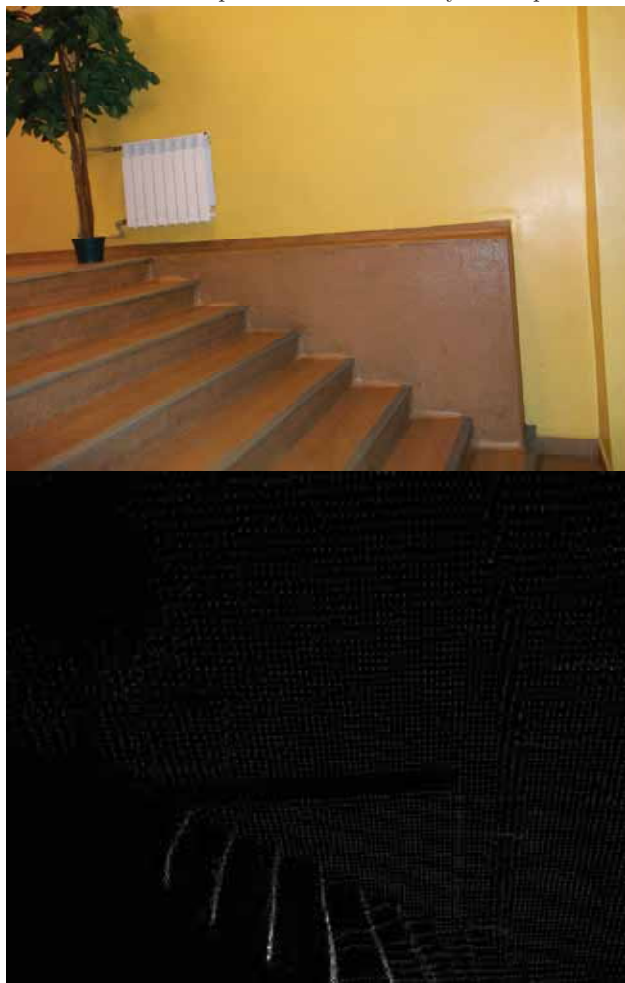


Fig. 4. Comparison of scanned area and visualized scanning data

Rys. 4. Porównanie skanowanego obszaru i zwizualizowanych danych pomiarowych

Placing the tripod with the module in various environments and conducting series of scans allowed to check dependencies between precision of measurements and characteristics of an obstacle, as well as environment parameters. As a reference were used results of 5000 tests performed by researchers from Autonomous Systems Laboratory in Zurich [6]. First conducted test compared results obtained during five scans with daylight, artificial light and in complete darkness. Differences in measured distances between all 15 results were similar and not exceeding 10 mm for a single point in a cloud. The second test was performed to verify precision. During all of the numerous scans in various test benches none of the materials was detected in its real distance from the sensor with an error smaller than 10 mm. In general dark coloured materials were localized further whereas bright coloured closer than their nominal position. The worst situations were observed for glass and mirrors, which can be explained with classical optics. Glass is transparent for light, so there was no difference in received data between closed and opened window. Light is reflected from mirrors so instead of distance to wall were a mirror hanged, laser range scanner detected objects that have been seen in the mirror.

Further research focused on behavior of the orientation correcting algorithm when disturbances caused change in spatial orientation of the module. With solely pitch change results did not proved that algorithm is working. Some verses of measurements were condensed, while others were sparse. When roll of the scanner was constantly changed during measurements a scattered point cloud was received. Series of tests proved that with those scans all obstacles were possible to identify, although small blank and uninvestigated spots appeared.

### 4. Conclusion

Developed 3D LIDAR is a functional module that might be very useful especially during indoor UAV missions. Received measurement data is unambiguous and all objects can be identified. Hokuyo URG-04LX scanner's precision is sufficient to apply obtained point cloud in anti-collision system. Unfortunately fixed and large time span 0.112 s between one line and the whole range scans forces significant reduction of the range and resolution to update information about UAV surroundings in less than 2 s. Such short time is required for any avoidance algorithm to work in a real time and allow aircraft to move smoothly without undesired hovering during each scan.

Improvements of the module would be conducted after in-flight tests that might reveal problems unpredicted during project and design processes. It was already proved during correction algorithms verifications that not all areas would be covered when an UAV was exposed to spatial orientation disturbances. Further researches of the 3D LIDAR would be focused on development of an avoidance algorithms as well as on a spatial stabilization of the module housing instead of using software correction algorithm.

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### Projekt miniaturowego, trójwymiarowego laserowego skanera przestrzeni dla BSP pionowego startu i lądowania

**Streszczenie:** Wykorzystując komercyjny, laserowy skaner wykonujący pomiary w jednej płaszczyźnie, opracowano moduł awioniczny umożliwiający uzyskanie trójwymiarowej chmury punktów obrazujących przestrzeń wokół statku powietrznego. Współrzędne sferyczne każdego z tych punktów przekazywane są do komputera pokładowego systemu awionicznego. W zależności od zaimplementowanego w nim algorytmu, odebrane dane mogą służyć do określenia obszarów niebezpiecznych dla lotu, wyznaczenia trajektorii lotu z ominięciem przeszkód lub wizualizacji otoczenia statku powietrznego. W artykule przedstawiono zastosowaną konstrukcję modułu awionicznego i opracowany algorytm pracy urządzenia, omówiono otrzymane wyniki oraz przedstawiono ograniczenia możliwości zastosowania modułu wynikające ze specyfiki zaproponowanego rozwiązania.

**Słowa kluczowe:** laserowy skaner przestrzeni, BSP, moduł awioniczny, system antykolizyjny

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